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PHYSIOLOGICAL, BIOMECHANICAL, AND MEDICAL ASPECTS OF LIFTING AND REPETITIVE LIFTING: A REVIEW

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The literature relating to physiological and medical lifting and repetitive lifting is reviewed. Studies on maximal lifting capacity and maximal acceptable lift (MAL, the amount of weight that can be lifted repetitively over and 8h period) show that as the height to which the load is lifted increases, the amount of weight lifted decreases. As lifting frequency increases, MAL decreases but power output increases. MAL of females is 50 - 70% of male values. Cardiorespiratory and metabolic studies demonstrate that VO_2, HR, V_E and ratings of perceived exertion increase in a linear manner with increases in the load or

frequency of lifting. The mechanical efficiency of repetitive lifting is 6-7%. MAL does not change with changes in the length or height of the load but as the load width increases, MAL decreases. $\dot{V}O_2$ and HR increase with increasing load length or width.

A biomechanical model for extimation of forces and torques at various joints is presented. Compressive forces on the L5/51 spinal segment are less for the squat lift (straight back, bent knees) than the stoop lift (straight back, bent knees). The free style and stoop techniques result in lower energy expenditures and higher power outputs than the squat.

Individuals involved in repetitive lifting are at risk for back injuries, falls, and contact type injuries. Various surveys have shown that about half of these injuries are due to violent movements, twists, or slips while carrying. The number of years involved in repetitive lifting may be a more important factor in back injuries than acute trauma. Injuries can probably be reduced by careful lifting in standardized postures, screening of individuals (using medical histories and isometric strength tests), and by proper engineering of the exercise area.

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FOREWORD

The importance of manual lifting in a military environment remains despite mechanization and advanced technology weapon systems. The flexibility of the human organism in lifting, carrying and placing objects far outstrips the limited movements of mechanical systems. When one considers the number of military tasks requiring lifting the human in the role of a manual material handler takes on great importance. The review presented here was undertaken as a first step in a project by this Institute to examine the physiological responses and limits during repetitive lifting. It was thought that a review of this nature would be of interest to individuals involved in manual material handling and could serve as a reference and idea source to investigators contemplating study in this area.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The literature relating to physiological and medical lifting and repetitive lifting is reviewed. Studies on maximal lifting capacity and maximal acceptable lift (MAL, the amount of weight that can be lifted repetitively over an 8h period) show that as the height to which the load is lifted increases, the amount of weight lifted decreases. As lifting frequency increases, MAL decreases but power output increases. MAL of females is 50 - 70% of male values. Cardiorespiratory and metabolic studies demonstrate that $\dot{V}O_2$, HR, $\dot{V}_E$, and ratings of perceived exertion increase in a linear manner with increases in the load or frequency of lifting. The mechanical efficiency of repetitive lifting is 6-7%. MAL does not change with changes in the length or height of the load but as the load width increases, MAL decreases. $\dot{V}O_2$ and HR increase with increasing load length or width.

A biomechanical model for estimation of forces and torques at various joints is presented. Compressive forces on the L5/S1 spinal segment are less for the squat lift (straight back, bent knees) than the stoop lift (straight back, bent knees). The free style and stoop techniques result in lower energy expenditures and higher power outputs than the squat.

Individuals involved in repetitive lifting are at risk for back injuries, falls, and contact type injuries. Various surveys have shown that about half of these injuries are due to violent movements, twists, or slips while carrying. The number of years involved in repetitive lifting may be a more important factor in back injuries than acute trauma. Injuries can probably be reduced by careful lifting in standarized postures, screening of individuals (using medical histories and isometric strength tests), and by proper engineering of the exercise area.

Physiological, Biomechanical, and Medical Aspects of Lifting and Repetitive Lifting: a Review

by

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INTRODUCTION

In 1978 the US Army Infantry School at Ft Benning, Georgia was tasked with the development of a list of physical task requirements for the 350+ military occupational specialities (MOS) in the Army. One striking characteristic of the resulting MOS physical task list (65) was the large number and variety of MOS that required some aspect of lifting and/or lifting and carrying. For example, the artillery MOS 13B requires lifting and carrying of projectiles weighing from 16-90kg a distance of 20m at a frequency of 100 times per day. The signal MOS 35R requires lifting of a 45kg computer by hand to a workbench. The engineering MOS 53B calls for 2 man teams to lift and carry 113kg chemical containers 25m and stack them 10 times per hour for 8h a day. The quatermaster MOS 43E requires troops to lift and carry 41kg ammunition boxes 6.7m once every 2 min for 8h. The medical MOS 91B calls for 2 man litter teams to position 180lb patients on a litter and evacuate them 250m, performing 4 round trips per hour. The quatermaster MOS 76X must lift and carry class B ration containers weighing 14-23kg 6m, 60 times per hour, 4h per day (65). These are only a few examples but they point out the variety of MOS that require lifting and the importance of lifting in a military environment.

The purpose of this report is to review the literature on various aspects of lifting. The presentation is divided into 2 major parts reviewing first the physiological and biomechanical aspects of lifting, followed by some medical aspects.

PHYSIOLOGICAL AND BIOMECHANICAL ASPECTS OF LIFTING

Five major variables can be isolated in the lifting and/or repetitive lifting of an object. These variables are : 1) the weight of the object lifted, 2) the height to which the object is lifted, 3) the frequency of the lift, 4) the size (dimensions) of the object lifted and, 5) the technique of lifting. Each of these variables will be treated in the following sections.

WEIGHT, HEIGHT, AND FREQUENCY OF LIFT

Many studies have confounded the factors of weight of the object, height of lift, and frequency of lift making the isolation of the influence of a single variable difficult. This subsection will first review the ways in which these 3 variables are measured then examine individual studies.

The weight a subject can lift can be quantified as either an absolute or relative load. An absolute load is simply the actual weight (for example 50 kg) that the subject is required to lift. The relative load is usually expressed in terms of a percentage of a one repetition maximum (1RM) or a maximum acceptable lift (MAL). The 1RM is the maximum amount of weight the subject can lift to a designated height. The MAL is the weight the subject is willing to lift for a prolonged period (described more fully later). The absolute load more closely approximates a "real world" situation since loads are not scaled to individual capabilities. However, cardiovascular and metabolic responses vary in a systematic manner with the relative load (13).

The height to which an object can be lifted can also be quantified in either a relative or absolute manner. An absolute height is the defined distance (for example 91 cm) to which the subject must raise the load. Relative height is usually defined in terms of the body dimensions of the subject . For example 3

relative heights used by many investigators are defined by Snook and Irvine (58): 1) the floor to knuckle height (FK), 2) the knuckle height to shoulder height (KS) and 3) the shoulder height to full arm reach (SA).

Lifting frequency is usually quantified in terms of lifts per minute. Some studies have quantified their results in terms of power (force * distance/time) and in some cases enough information is given with which to calculate frequency.

Maximal Lifting Capacity

Several studies have examined human capacity in a single maximal lift to different heights. Most studies use a variation of the 1RM procedure whereby the weight in the box is progressively increased until the subject is unable to lift the box. The last weight successfully lifted is defined as the maximal lift capacity (MLC). These studies are somewhat confounded by different instuctions given to subjects and a variety of box sizes.

Emanuel et al. (16) instructed 19 males (17-28 yrs old) to "lift the greatest weight possible without a feeling of possible injury." The task required subjects to lift a 30 x 65 x 15 cm ammo case with handles from the floor to a platform. Weight lifted decreased as height increased. The weight lifted was 105, 88, 54, 37, and 26 kg as height increased from 30, 61,91, 122, and 152 cm, respectively. The greatest decrease in weight was between the 61 cm and 91 cm lift, the point at which most subjects began to use primarily their arms.

McDaniel et al. (31) tested 1066 male and 605 female Air Force basic trainees on an incremental weight lifting apparatus (modified Air Force Factor X). Subjects were instructed to lift as much weight as possible from the floor to either 183 cm or to arms reach and from the floor to elbow height. They were told to stop if they thought they might hurt themselves. Weight was increased in 10 lb increments. For the 183 cm lift, males elevated 52 ± 5 kg while females

lifted 26 ± 5 kg; for the elbow height lift males and females elevated 59 ± 11 kg and 31 ± 6 kg, respectively.

Jorgensen and Poulsen (26) had 4 male and 4 female subjects (21-33 yrs old) lift a 30 x 35 x 26 cm box with handles from the floor to a 61 cm height. Subjects were instructed to use a bent back but also to keep the load as close to the body as possible. MLC for the males was 86 ± 16 kg and for the females, 56 ± 6 kg.

Sharp et al.(52) had 181 male and 41 female Army basic trainees (21 ± 3 yrs old) lift a 47 x 23 x 31 cm box with handles to a height of 132 cm. Subjects were required to perform a "maximal safe lift" by using flexed hips, straight back and straight arms and to avoid jerking and hyperextension of the back. Males lifted 57 ± 10 kg while females lifted 33 ± 6 kg. Wright et al. (66) report a pilot study using similar techniques in which males (N = 54) lifted 78 ± 12 kg and females (N = 26) lifted 36 ± 9 kg.

Legg and Myles (42) had 10 British soliders (24.1 yrs old) lift a 50 x 26 x 11 cm box with handles to 40% of their height (69 cm). MLC was defined as the greatest load that could be lifted "cleanly" from the floor. An average value of 89 ± 20 kg was found. In a second study (41) using similar techniques a value of 90 ± 13 kg was obtained.

In a related study Poulsen (47) reasoned that the back extensor muscles were the weakest muscle group involved in lifting. She had 21 male and 24 female subjects lift a 30 x 35 x 26 cm box with handles from floor to knuckle height (FK) and from floor to head height. Subjects also performed an isometric strength test of the back extensor muscles. Correlations between MLC (FK) and isometric strength were 0.72 and 0.78 for males and females respectively. The prediction formula was MLC = 1.10 (back strength) + 0.42 for males and MLC = 0.95 (back strength) - 8.0 for females (48). Correlations between MLC

(floor to head height) and isometric strength were 0.66 and 0.62 for males and females, respectively. A separate pilot study (28) found a correlation of 0.85 between MLC (FK) and isometric strength of the back extensors. However a study of 251 male and 46 female basic trainees at Ft Stewart, Georgia found correlations of only 0.55 and 0.47, respectively (66).

To summarize, studies on MLC show that as the height to which the object is lifted increases, the amount of weight lifted decreases (16). Lifting from the floor to a height of 61-69 cm various studies have obtained MLC of 86-90 kg for males. (16,26,41,42). Lifting from the floor to 122-132 cm values of 37-78 kg have been obtained for males and 33-36 kg for females (52, 66). MLC from the floor to waist height was moderately correlated with isometric back strength in two studies (28, 47) although this was not confirmed in a subsequent study (66). Various studies (26,31,52,66) have found the MLC of females to be from 46% (66) to 65% (26) of the male value.

Maximal Acceptable Lift

In order to make results from the laboratory more revelent to industrial situations, Snook and co-workers (53-61) have pioneered studies using a psychophysical methodology. The subject is asked to determine a load that he/she could work at without straining himself, becoming unusually tired, overheated, weak or out of breath. In the procedure finalized by Snook, Irvine and Bass (61) the subject is given 2, 20 minute periods during which he may add or remove lead shot from a tote box. When the subject is satisfied with the weight, this load is called the maximal acceptable lift (MAL).

Using the psychophysical methodology Snook and Irvine (58) had 9 male subjects lift a 34 x 48 x 14 cm box from the floor to knuckle height (FK), from knuckle height to shoulder height (KS) and from shoulder height to arms reach (SA). The 50th percentile values for MAL were 30, 28, and 27 kg, respectively.

Snook, Irvine, and Bass (61) and Snook and Ciriello (56) tested 28 male and 15 female industrial workers lifting the same size box to the same heights as the previous study. In this study subjects adjusted not only the load in the box but also the frequency of lifting. The 50 percentile male had a MAL of 25 kg (FK, 76 cm), 24 kg (KS, 140 cm) and 22 kg (SA, 196 cm). For females these values were 17 kg (70 cm), 16 kg (132 cm) and 13 kg (188 cm), respectively (69%, 64% and 60% of the male values). The 50 percentile power output of the men were 44.5 kgm/min (FK), 64.7 kgm/min (KS) and 51.2 kgm/min (SA). For females these values were 33.3 kgm/min, 46.3 kgm/min and 34.8 kgm/min respectively (75%, 72% and 68% of the male values).

Garg and Saxena (20) used the psychophysical methodology to determine the MAL but used specific lifting frequencies of 3, 6, 9, and 12 lifts/min. They tested 6 male students (21-34 yrs old) and had them lift a 38 x 20 x 15 cm box to a height of 50 cm. Regardless of lifting technique (3 were studied) the MAL decreased with increasing frequency but the power output increased with increasing frequency. In the free-style technique (in which subjects lifted any way they wanted) MAL was 23 kg, 20 kg, 16 kg, and 14 kg, respectively; power outputs were 34.3, 59.3, 73.6, and 81.6 kgm/min, respectively. For the straight back bent knee technique MAL was 19, 15, 13, and 11 kg, respectively; power outputs were 28.3, 45.3, 58.6, and 66.0 kgm/min, respectively.

Snook (54) found results similar to Garg and Saxena (20). In testing 28 male industrial workers lifting Snook's standard box to the 3 heights described above (58), MAL decreased as the frequency increased. Not enough information is given to calculate power outputs precisely but rough estimates indicate that as the frequency of lifting increased, power output increased.

Switzer (62) instructed 75 male students (19.5 yrs old) to find a reasonable amount of weight that could be lifted for a long period. This was very similar to

the psychophysical methodology. Subjects lifted a 30 x 15 x 30 cm box either 46 cm, 107 cm, or 158 cm. As the height to which the object was lifted increased, the weight lifted decreased from 61 kg to 38 kg to 28 kg, respectively. The greatest decrease was between the two lower heights, the point at which the arm muscles came into greater use. As the height of the subject increased, they were able to lift more weight.

Legg and Myles (42) used the psychophysical methodology to determine the MAL for 10 British soliders to a height 40% of each individuals body height (69 cm in this study). The MAL was 17.5 $\pm$ 3.7 kg which was 20.6 $\pm$ 5.7% of the MLC.

The influence of starting heights on MAL was studied by Kassab and Drury (40). A 50.8 cm cube (a non compact load) was lifted by 12 male and 8 female subjects. The height from which the cube was lifted was either 0, 60, or 120 cm; the height to which the cube was lifted was 60, 120, or 180 cm. MAL generally decline as the height (either from or to) increased. For the 0 - 60, 0 - 120 and 60 - 120 cm lifts the female MAL was 52, 53, and 58%, respectively, of the male MAL.

The studies on MAL are summarized in Table 1. As the height of the lift increases the amount of weight lifted decreases but only slightly (40, 56, 58, 61,62). As the frequency of lifting increases the load lifted systematically decreases (20, 54) but the power output increases (20). At the FK, KS, and SA lifting heights, female MAL are about 50 - 70% of the male values. (40, 56)

Cardiovascular and Metabolic Studies on Lifting

Physiological studies on repetitive lifting have centered around measurement of oxygen uptake and HR. The findings are similar to those of other studies of rhythmic exercise. In one study by Miller et al. (33) it was hypothesized that since lifting resulted in high interthoracic and interabdominal

TABLE 1. Summary of Studies on MAL.

	Ss**	Load (kg)	Frequency (lifts/min)	Distance (m)	Power (kgm/min)
Snook, Irvine, and Bass (61)	28M	25	2.34	0.76(FK)	44.5
		24	1.92	1.40(KS)	64.7
		22	1.19	1.96(SA)	51.2
Snook and Ciriello (56)	14F	17	2.80	0.70(FK)	33.3
		16	2.19	1.32(KS)	46.3
		13	1.42	1.88(SA)	34.8
Garg and Saxena (20)***	6M	23	3	0.50	34.3
		20	6	0.50	59.5
		16	9	0.50	73.6
		14	12	0.50	81.6
		19	3	0.50	28.3
		15	6	0.50	45.3
		13	9	0.50	58.6
		11	12	0.50	66.0
Snook and Irvine (58)	9M	30		(FK)*	
		28		(KS)*	
		27		(SA)*	
Switzer (62)	75M	61		0.46	
		38		1.07	
		28		1.58	
Legg and Myles (42)	10M	17.5		0.69	
Kassab and Dury (40)	12M	27		0-0.60	
		24		0-1.20	
		18		0-1.80	
		29		0.60-1.20	
		19		0.60-1.80	
		20		1.20-1.80	
	6F	16		0-0.60	
		13		0-1.20	
		8		0-1.80	
		15		0.60-1.20	
		8		0.60-1.80	
		8		1.20-1.80	

*Distance not given in article

**M = Males, F = Females

***First 4 rows are for the freestyle technique, last 4 are for the straight back, bent knee technique (these techniques are discussed further on pages 16-23).

pressures the normal cardiovascular relationships expected from rhythmic exercise may not apply. In this study 18 male subjects (36.7 $\pm$ 11 yrs old) lifted and carried a 30 x 30 x 46 cm box to a height of 1.5 m (the lift began 0.67 m from the floor). The weight of the box varied from 6.7 to 20.4 kg. Two power outputs were examined: 1) "light work", 49 kgm/min (6 lifts/min), and 2) "heavy work", 49-312 kgm/min (10 lifts/min). Exercise sessions were 15, 30 or 40 min long and expired gases were collected at 12, 25 and 35 min, respectively. HR were obtained each min. Steady state HR were obtained 1 - 16 min after light work began ($\bar{x}$ = 4.8 $\pm$ 4.8 min) and 3 - 27 min after heavy work began ($\bar{x}$ = 13.7 $\pm$ 7.0 min). No data on time to reach steady state $\dot{V}O_2$ is reported. HR and $\dot{V}O_2$ increased linearly with increasing power output suggesting that cardiovascular functions respond to repetitive lifting in a manner similar to the responses triggered by treadmill, bicycling and arm crank exercise.

Legg (41) had 8 male soliders (25.5 $\pm$ 4.0 yrs old) repetitively lift a 46 x 25 x 10 cm box with handles to 40% of each individual's body height (69 cm in this study). Subjects lifted 25% of the MLC at frequencies of 8, 10, and 12 lifts/min; 50% MLC at 4, 6, and 8 lifts/min; 75% MLC at 2, 3, and 4 lifts/min. All 9 lifting trials were performed to exhaustion and $\dot{V}O_2$ was taken every 10 min of exercise. It was found that as the % MLC or the number of lifts/min increased, the time to exhaustion decreased. $\dot{V}O_2$ increased with both increasing % MLC or increasing frequency.

Snook and Irvine (60) had 9 male industrial workers (26 - 37 yrs old) lift a 48 x 34 x 14 cm tote box to 3 heights: FK, KS, or SA. The box was loaded with either 16 or 23 kg. HR were monitored during a 1 h period while subjects adjusted the frequency of lifting. At the two higher lifts (KS and SA) no significant HR differences were found either for the 2 loads or heights ($\bar{x}$ = 99 $\pm$ 11 beats/min). The lower lift (FK) resulted in HRs that were

significantly different from the other 2 heights but no difference between loads was found ($\bar{x}$ = 112 ± 10 beats/min). In a field study of 12 workers performing string lasting of shoes (involving upper body exercise) a HR of 100 ± 15 beats/min was found.

Jorgensen and Poulsen (26) had 4 male and 4 female subjects lift a 20 x 35 x 26 cm box to a height of 0.61 cm for 20 min. Subjects lifted 10% MLC at 6, 9, and 12 lifts/min, 25% MLC at 6, 7, and 8 lifts/min, 50% MLC at 4, 5, and 6 lifts/min and 75% MLC at 2, 3, and 4 lifts/min. HR and $\dot{V}O_2$ were collected at 5 and 15 min of exercise. On a separate occasion, a cycle ergometer test was used to predict $\dot{V}O_2$ max. Relative energy cost increased either with increasing load or increased frequency of lifting. Maximal lifting frequency at 50% $\dot{V}O_2$ max increased with an increase in predicted $\dot{V}O_2$ max suggesting that $\dot{V}O_2$ max may be a limiting factor in the maximal frequency of repetitive lifting at 50% $\dot{V}O_2$ max. Mechanical efficiency (calculated as Δ Power/(Δ $\dot{V}O_2$ * 4.9 * 427)) ranged from 6.1 to 7.1% in 4 subjects.

Petrofsky and Lind (45) trained 4 male subjects in repetitive lifting of a 30 x 18 x 18 cm over a 12 week period. The boxes were loaded with 7, 23, or 36 kg and subjects lifted at rates (4 - 70 lifts/min) equivalent to 50% of their estimated $\dot{V}O_2$ max for periods up to 4 h. The lift was 60 cm and was performed with a freestyle technique. Testing was conducted only post training and consisted of lifting the same box with the same loads at different frequencies for 4 min. Frequencies were increased in a step-wise manner in order to ultimately achieve a "lifting $\dot{V}O_2$ max." HR's and expired gas samples were collected in the last 20 sec of exercise. $\dot{V}O_2$, $\dot{V}_E$, and HR increased both with increasing frequency and increasing weight. Subjects reported that at the lower weights the limiting factor was the inability to raise and lower the body rapidly enough while at the higher frequencies the limiting factor was fatique in the arm and

hands. A graph of power output vs. $\dot{V}O_2$ showed no evidence of a "leveling off" of $\dot{V}O_2$ at the highest frequencies.

In a second study (46) 3 of these 4 trained subjects lifted the same box for 1 h at frequencies equivalent to 25, 40, 55 and 70% $\dot{V}O_2$ max. Loads were held constant at each intensity and were either 7, 23, or 36 kg. HRs were obtained at 4, 29, and 58 min of exercise and finger tip blood samples were taken 15 sec post exercise for lactate analysis. Isometric endurance (40% maximum voluntary contraction (MVC)) of the handgrip (HG) and arm - back muscles was assessed several days prior to the repetitive lift and 30 sec post lifting. Results were as follows: HRs did not rise during the 1 h exercise at 25 or 40% $\dot{V}O_2$ max but demonstrated a sharp linear rise at 55 and 70% $\dot{V}O_2$ max. Post exercise lactates showed little change at 25 or 40% $\dot{V}O_2$ max but much higher levels were seen at 55 and 70% $\dot{V}O_2$. Isometric endurance of the HG and arm-back muscles were reduced in a systematic manner with either increasing load (holding exercise intensity constant) or increasing exercise intensity.

Legg and Myles (42) determined the $\dot{V}O_2$ and HR of 10 British soliders (24.1 $\pm$ 5.7 yrs old) during repetitive lifting of a 50 x 26 x 11 cm box to 40% of body height (0.69 m for the group). Lifts of 0.75, 1.0, 1.25 and 1.5 of MAL (13.1, 17.5, 21.9 and 26.3 kg) were studied at a rate of 2.5 lifts/min for 5, 15 and 30 minute periods (power outputs = 22.6 to 45.3 kgm/min). Energy expenditure and HR increased in a linear manner as a function of the MAL. Steady state HRs were achieved within 5 min.

Asfour et al. (1) had 10 male students train for 6 weeks using a variety of flexibility, muscular strength, and cardiovascular training methods. These subjects were then given a series of repetitive lifting tests. Three box weights (6.8, 13.6 and 20.5 kg), 3 lifting frequencies (3, 6 and 9 lifts/min), and 3 lifting

TABLE 2. Power outputs for the Asfour et al. (1) study (kgm/min).

Load (kg)	Lifting Frequency (lifts/min)	Lifting Heights (cm) 0-76	76-124	0-124
	3	15.5	9.8	25.3
6.8	6	31.0	19.6	50.6
	9	46.5	29.4	75.9
	3	31.0	19.6	50.6
13.6	6	62.0	39.2	101.2
	9	93.0	58.8	151.8
	3	46.7	29.5	76.3
20.5	6	93.5	59.0	152.5
	9	140.2	88.6	228.8

heights (0 - 76, 76 - 127, and 0 - 127 cm) were studied. $\dot{V}O_2$ and HR were collected for 3 min beginning after either 5 or 11 min of exercise. Ratings of perceived exertion (RPE) were obtained at the end of the 13 min exercise bout. HR and RPE increased in a relatively linear manner with an increase in the load or lifting frequency (no $\dot{V}O_2$ values were reported). The 76 - 127 cm lift had the lowest HR and RPE while the 0 - 127 cm lift had the highest. The calculated power outputs (shown in Table 2) were lowest for the 76 - 124 cm lift and highest for the 0 - 124 cm lift. The overall correlation between HR and RPE was 0.67 (range 0.43 - 0.67) and between $\dot{V}O_2$ and RPE it was 0.73 (range 0.57 - 0.73).

SUMMARY. No studies have been performed to determine when a steady state of oxygen consumption or $\dot{V}_E$ is achieved during repetitive lifting. Steady state HR's may be reached before 5 min at low power outputs (22.6 - 49.0 kgm/min) (33, 41) but at higher power outputs HR's may continue to increase throughout the exercise bout (33). Collection of expired gas samples and/or HR's have begun in various studies at 3.7 min (45), 5 min (1, 26, 41), 10-11 min (1, 41) and at 12 min (33). Generally, these studies have indicated that $\dot{V}O_2$, HR, and $\dot{V}_E$ increases in a linear manner with increases in either the weight or the frequency of the lift for lifting heights of 0 - 1.27m (1, 26, 33, 41, 45). HR's are lower when lifting in the KS and SA height range than in the FK height range (1, 60). Blood lactates do not appear to change up to about 40% of the lifting $\dot{V}O_2$ max but at 55% of the lifting $\dot{V}O_2$ max and higher, elevated levels are seen (46). Isometric endurance at 40% MVC is reduced in a systematic manner with increases in power output (46). Mechanical efficiency of repetitive lifting appears to be about 6-7% (26). RPE's increase with increasing load or frequency (1). At < 50% $\dot{V}O_2$ max aerobic capacity may be a major limiting factor in the maximal frequency of repetitive lifting (26). At higher exercise intensities there is a

large decline in isometric endurance at 40% MVC and subjects complain of local upper body fatigue suggesting muscular strength may be more important here (46).

SIZE OF OBJECT LIFTED

The MAL and physiological responses to the lift have been shown in a few studies to be influenced by the charateristics of the object lifted. Four major variables have been investigated: 1) box length or dimension of the box in the transverse plane, 2) box width or dimension of the box in the sagittal plane, 3) box height or dimension of the box in the frontal plane and, 4) coupling (the presence or absence of handles on the box).

Box Length

Mital and Ayoub (34) investigated box lengths of 36, 51, and 66 cm. Subjects were required to repetitively lift 3 loads (11, 16, and 20 kg) from FK or KS height for 12-15 minutes at either 2 or 6 lifts/min. HR and $\dot{V}O_2$ were collected near the end of the exercise period. $\dot{V}O_2$ was significantly different at all 3 box lengths and HR's were significantly different between the 36 and 51 cm lengths and the 36 and 66 cm lengths. Ciriello and Snook (11) found no significant differences in MAL between 57 and 89 cm long boxes and Garg et al (18) found no significant differences in MAL between boxes 35 and 63 cm long.

Box Width

In Mital and Ayoub's study (34), described above, box widths of 38, 51 and 64 cm were examined. HR and $\dot{V}O_2$ was significantly lower during lifting of the 38 cm box compared to the 51 and 64 cm widths but the latter 2 were not significantly different from one another. Ciriello and Snook (11) found significant differences in MAL among box widths of 36, 49 and 75 cm when

lifting from FK but not KS. HR's and $\dot{V}O_2$ increased significantly with increasing box width. No multiple comparison tests were performed to see which box widths were different from one another. Garg and Saxena (19) had 10 college students lift boxes of varying width (38, 51 and 64 cm) from the floor to a height of 76 cm. Length and height of the boxes were 25 and 51 cm, respectively. The 38 cm width resulted in a greater MAL than the 51 and 64 cm boxes but the latter 2 did not differ from one another. In a study by Garg et al. (18) MAL was significantly higher with a 35 cm wide box compaired to a 63 cm wide box.

Box Height and Coupling

Box height was investigated in the study by Mital and Ayoub (34) described above. Heights of the boxes were 20 and 30 cm and these had no significant effect on HR or $\dot{V}O_2$.

Garg and Saxena (19), in the study described above, used 2 boxes 51 x 38 x 25 cm. Handles were placed on one box but not another. MAL of the box with couples was significantly higher (12%) than the box without couples. Mital and Ayoub (34) found higher $\dot{V}O_2$ and HR when couples were not present on the box.

Summary

MAL does not vary when box length is changed in a 32 cm range or box height is changed in a 10 cm range (18, 11, 34). However, MAL is greater with a more compact box width (~ 36 cm) than with a greater box width (49 - 75 cm) (11, 18, 19). Handles on boxes increase the MAL (19). HR and $\dot{V}O_2$ increase with increasing box length or width (11, 34) and are both higher if the box does not have handles (34).

LIFTING TECHNIQUE

Since the 1930's the straight back, bent knee lifting technique (the "squat") has been advocated in order to reduce injuries in lifting (7). Two other lifting techniques are the bent back, straight knee (the "stoop") and the free style (in which individuals chose the method most suitable to themselves). This subsection will first examine the biomechanics of lifting then review biomechanical and metabolic studies on lifting techniques.

Biomechanics of Lifting

Lifting is a whole body motion involving almost every joint in the body. In the FK lift, the ankle, knee, hip, intervetebral, and shoulder joints are involved. In the KS and SA lifts the shoulder, elbow, wrist, and intervetebral joints are involved. This subsection will concentrate on the FK lift and the L5/S1 spinal joint in order to illustrate the factors involved in the mechanics of lifting. It should be noted that this is only one type of lift and only one joint involved in the lifting process. It serves to illustrate the complexitites involved in the mechanics of lifting and exemplifies a method for studying other types of lifts and joints involved in these lifts.

The spine is not a single joint but rather a series of small joints with flexible articulations (intravertebral discs) between them. Because a great number of back problems arise at the L5/S1 segment, this is the joint that has been most often studied and is the one that will be examined here. Figure 1 is a representation of a man lifting a load showing the forces and torques involved. The position shown in figure 1 is a static one: no movement is involved. In order for this figure to be in equilibrum the forces tending to cause moments (torques) in the clockwise (CW) direction must be balanced by the forces tending to cause moments in the counterclockwise (CCW) direction. Torque equals force times

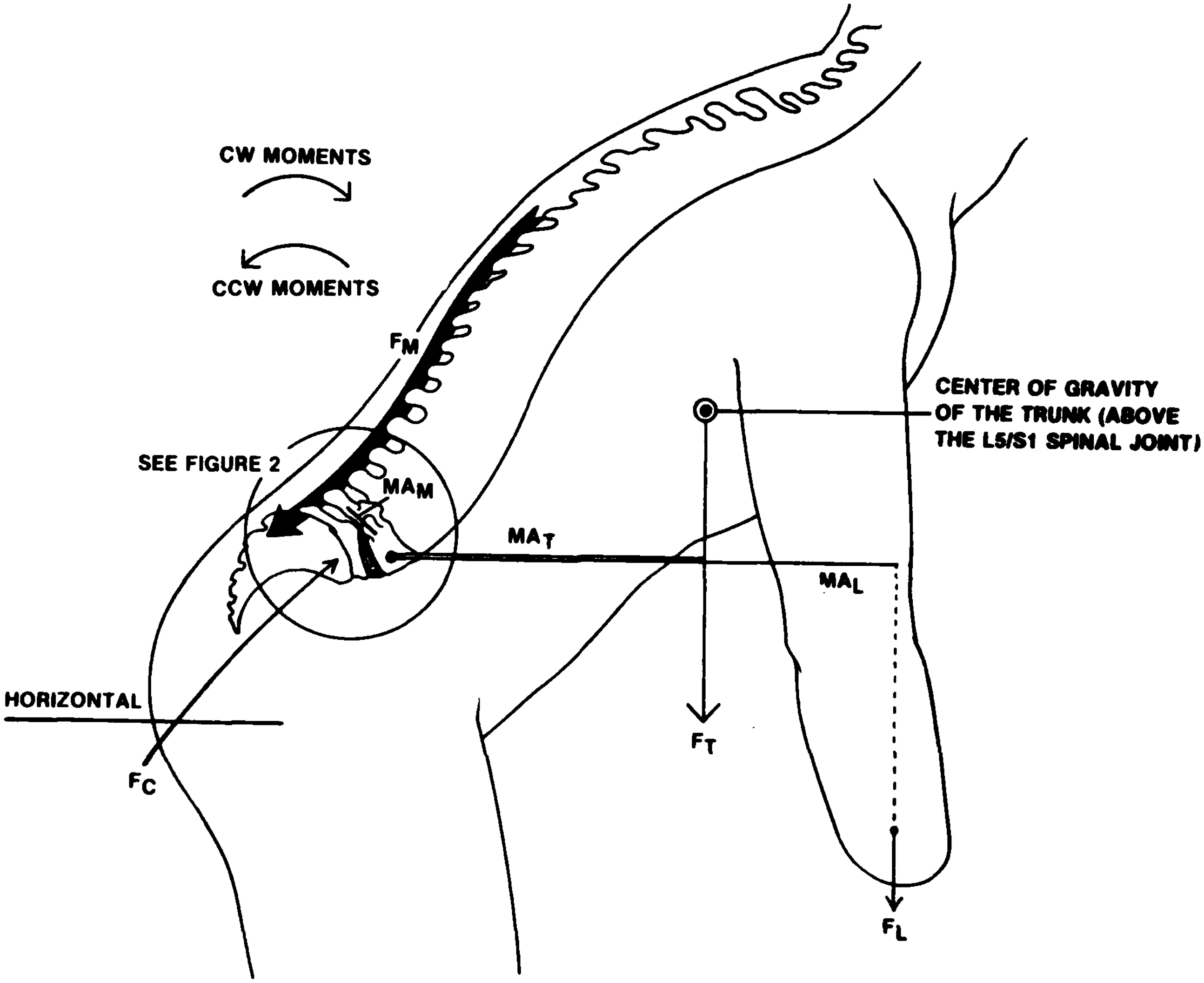

FIGURE 1. FORCES AND TORQUES ACTING ON THE BODY IN LIFTING A LOAD. F_M=FORCE PRODUCED BY THE MUSCLES; MA_M=MOMENT OF THE ARM OF THE MUSCLES; F_T=FORCE OF THE TRUNK; MA_T=MOMENT ARM OF THE TRUNK; F_L=FORCE OF THE LOAD; MA_L=MOMENT ARM OF THE LOAD; F_C=COMPRESSIVE FORCE ON THE L5/S1 JOINT. MODIFIED FROM CHAFFIN AND PARK (10).

the lever arm of the force. Torque in the CW direction is caused by the weight of the object lifted (multiplied by its lever arm) and the body weight above the L5/S1 spinal segment (multiplied by its lever arm). These 2 forces must be balanced by forces in the CCW direction produced by the back muscles acting on the lever arm of the spinous processes (Figure 2). Thus:

$$\text{CW moments} = \text{CCW moments}, \quad \text{(eq.1)}$$

$$MA_L * F_L + MA_T * F_T = MA_M * F_M, \quad \text{(eq.2)}$$

where MA_L = moment arm of the load, F_L = force of the load, MA_T = moment arm of the trunk, F_T = force of the trunk, MA_M= moment arm of the muscles, F_M = force produced by the muscles. Large torques (240NM) are produced at the L5/S1 joint when lifting a 50 kg load. Since the MA_M (the vertebral spinous processes) are very short (5 cm) very large forces must be produced by the muscles of the back (primarily the erector spinal) in order to counteract the forces in the CW direction. These large forces are the source of compressive forces on the L5/S1 disc (10).

Assume the following: F_T= 50 kg, MA_T= 0.20 m, F_L= 50 kg, MA_L= 0.30 m, MA_M= 0.05 m. Solving equation 2 for F_M yields a value of 500 kg or 4843 N. Thus the trunk extensor muscles must exert this force in order to maintain the body in equilibrum when lifting a 50 kg load.

The model presented above is a simple one and ignores the fact that lifting is a dynamic motion. If the dynamic aspect is considered the factors of moment of inertia and angular acceleration would have to be added to each force in the CW direction further increasing the moments in this directions. Also ignored is the intra-abdominal pressure (IAP). Bartelink (6) was probably the first to hypothesize that IAP may be important in the mechanics of lifting. He noted

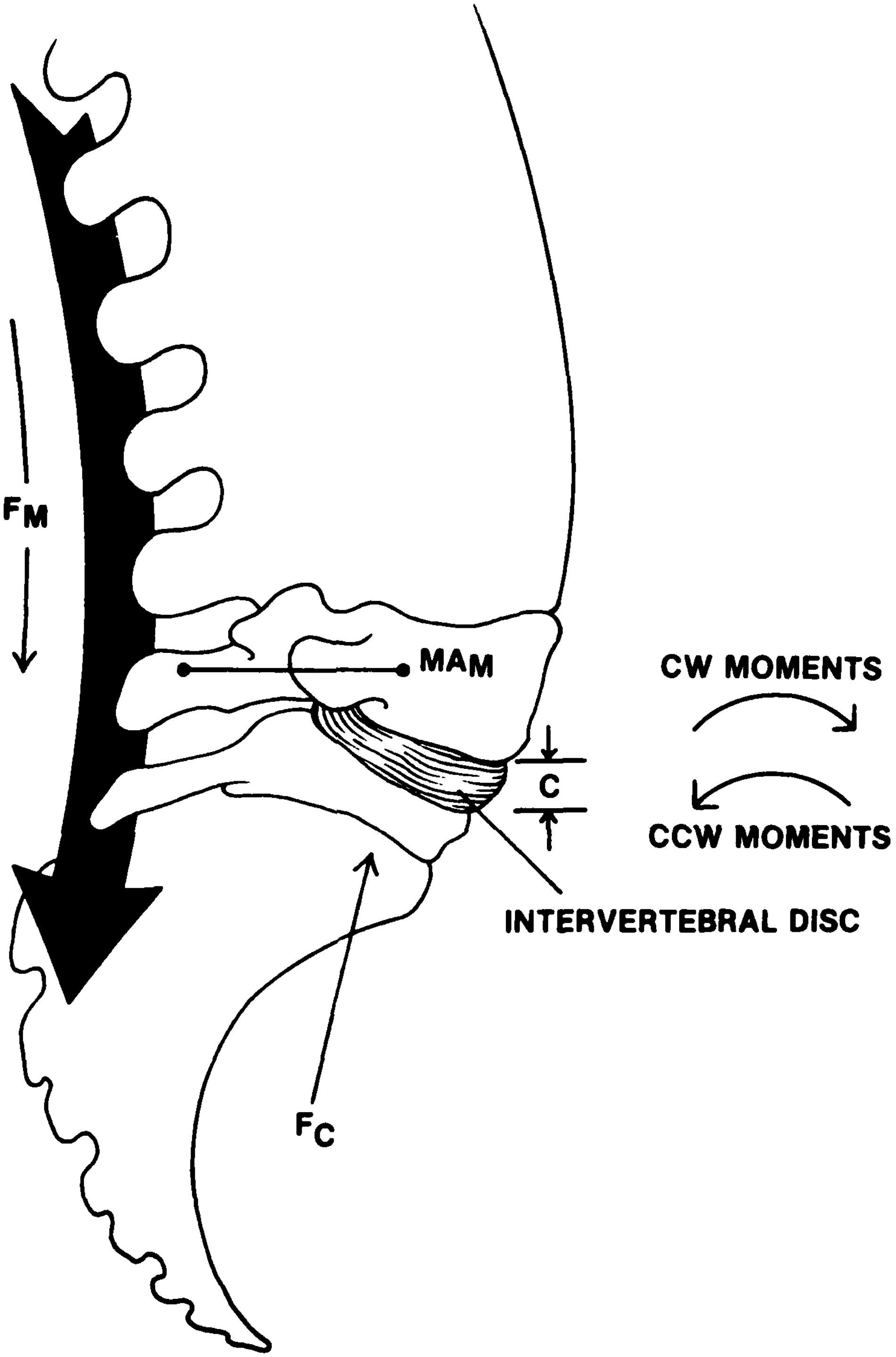

FIGURE 2. FORCES AND TORQUES ACTING AT THE L5/S1 SPINAL SEGMENT. C=COMPRESSION AT THE DISC; F_M=FORCE PRODUCED BY THE MUSCLE; F_C=COMPRESSIVE FORCE; MA_M=MOMENT ARM OF THE MUSCLE.

that the IAP increased as the weight lifted increased or with different degrees of bending. In extreme trunk flexion IAP was high and this pressure decreased as subjects moved to a fully extended trunk. Bartelink reasoned that a raised IAP could produce a force under the diaphram that could be transmitted to the thoracic spine by means of the ribs. This force could balance a portion of the forces produced by the lifting of a load. Viewed in another way, the abdominal cavity could be pictured as a balloon connected at the top to the costal margins and at the bottom to the pelvis. In lifting, the balloon is blown up and absorbs some of the weight of the load (and the trunk) transmitting this weight to the pelvis. Thus increased IAP decreases the load on the spine.

It is worth emphasizing again that the factors mentioned above refer only to one type of lift and one joint. Chaffin (8) has presented a two dimensional computerized biochemical model of lifting that takes into account all the factors mentioned above except the dynamic aspect of the lift. The static forces and torques at six joints and a number of joint positions can be estimated. Estimates for individuals can be obtained from this model by inputting the individuals height, weight, and 4 segmental lengths. For example, referring to Figure 1 for symbols, the F_C can be estimated by the formula

$$F_C = (F_T + F_L)/\sin\ \alpha + F_M - F_A$$

where F_A is the IAP. F_A is predicted from the hip angle, hip torque and diaphramic area. Assuming an α angle of 66^o and a load of 50 kg, the F_C at the L5/S1 spinal segment for a 50th percentile man is 5598N (578 kg).

F_C that can be tolerated by the vetebral column have been estimated from compressive tests on cadaver spinal segments (6, 14, 17, 44). Perry (44) tested 2 vetebrae systems (with discs) from 16 subjects under age 40 taken soon after

death. The mean ($\pm$ SD) F_C tolerated by the segments before fractures or disc failures occured were 7535 ($\pm$ 1831) N. Eie (14) showed that F_C failures occured at 6779N in a 27 yr old subject and from 5085 to 6247N in a 58 yr old subject. Chaffin and Park (10) in a review on the subject report that, generally, data on individuals under 40 show large variations but the mean value is 6603 N. They note that in most studies the discs do not rupture if they are healthy but rather the cartilagerous endplates of the vertebral segments fail. They suggest that in the normal body these structures may fail first and these failures may alter the metabolism of the discs. The degenerated discs would have a reduced capacity to withstand compressive loads and would ultimately fail.

F_C with Different Lifting Techniques

Ekholm et al. (15) reviewed several papers on compressive forces at the L5/S1 segment considering the IAP. The values are presented in Table 3. Ekholm et al. (24) used cinematography to estimate loading moments (F_L * MA_L) and F_C on the L_5/S_1 spinal segment. Fifteen subjects were photographed while lifting 12.8 kg from the floor to the height of each subject's umbilicus. Three lifting postures were studied: the stoop, the squat with the load in front of the knees, and the squat with the load close to the pelvis. The estimated loading moment of force on the L_5/S_1 segment was 217, 200, and 160NM, respectively. The estimated F_C on the L_5/S_1 disc with the IAP considered was 3182, 3540, and 2830N, respectively. Thus the squat with the load close to the pelvis resulted in the lowest loading moment and least compressive force on the L_5/S_1 joint.

Physiological Responses to Different Lifting Techniques

Only two studies were found examining physiological responses to different lifting techniques. Garg and Saxena (20) had 6 male college students (ages 21-34

yrs) lift a 38 x 20 x 15 cm box, 0.5 m (from the floor) at frequencies of 3,6,9, and 12 lifts/min. At each lifting frequency, three lifting techniques were used: the stoop, squat, and free-style. Subjects were asked to adjust the load using the psychophysical methodology and during the last 5 min of the adjustment period expired gases were collected. At all lifting frequencies the MAL and power output was highest for the free-style technique while the stoop was higher than the squat. At all lifting frequencies energy expenditure was highest for the squat while the stoop and the free-style did not differ from one another except at the higher power outputs where the free-style resulted in a lower energy cost.

Brown (7a) examined energy expenditure during lifting in 4 different postures. The postures were: a) erect with hands above shoulder height; b) erect with hands about at the waist; c) body slumped, hands below the knees; d) body bent 45°, hands level with the knees. Subjects lifted a 1kg weight 10 cm at 19 lifts/min. Energy expenditures were 3.02, 3.14, 3.61, and 4.19 kcals/min for postures b, a, c, and d, respectively. In a second series of experiments 4 subjects lifted weights ranging from 5 - 40 kg using either a stoop, squat, or freestyle lifting technique. No differences in HR were noted but at all weights, the stoop had the lowest energy expenditure and the squat had the highest.

Summary

The 3 major lifting techniques are the squat (straight back, bent knees), the stoop (straight knees, bent back) and the free-style. It is possible to estimate the forces and torques during lifting at a variety of joints and an example of the factors involved in an estimate at the L5/S1 spinal segment is given. A computerized biomechanical model of lifting has been developed by Chaffin (8) that provides estimates of forces and torques at 6 joints if the height, weight and 4 segment lengths of the individual are provided. Using this model, the 50th

percentile male, lifting a load of 50kg produces an estimated F_C on the L5/S1 spinal segment of 5598N. Compressive tests of cadaver spinal segments have shown that an average F_C of 6603-7535N can be tolerated before the segments fail (8, 14, 44). Estimates of F_C when lifting 12.8kg shows that the squat produces less F_C than the stoop (15). The free-style and stoop lifting techniques result in lower energy expenditure and higher power output than the squat (7a, 20).

TABLE 3. F_C with Different Loads Estimated from a Number of Studies (15).

Load (kg)	F_c(N)	F_C(kg)
130	4169	430
91	6596	681
50	5598	578
45	5658	584
25	3544	366
20	2042-3178*	211-328*
13.6	1833-2785*	189-288*
12.8	2830-3540*	292-366*

*Dependent on lifting style

MEDICAL ASPECTS OF LIFTING

MATERIAL HANDLING INJURIES

There are very few prospective studies that have associated injuries with the repetitive lifting of objects despite the fact that there is no absence of opinion on the subject (50). Many feel that a high incidence of disc disease among those engaged in heavy manual labor is strong evidence of a causal relationship between back injuries and lifting (3). Several survey studies have been conducted but suffer from a plethora of problems as described by Anderson (3). First, many of these studies are retrospective and tend to be unreliable when they depend on the memory of the subjects. Second, it is difficult to classify many of the injuries described by subjects. "Back pain" for instance has over 30 different labels in the International Classification of Diseases making compilation of statistical data difficult. Third, there is little standardization of statistics making meaningful comparisons difficult from one study to the next. Lastly, many studies classify physical effort into catagories like "light" and "heavy" which do not really address the type of work performed. With these qualifications in mind, it is possible to discuss the studies relating injury to repetitive lifting.

The Department of Labour of Great Britian found that accident rates due to lifting, carrying, pushing and pulling in 1940 was 7.9 per 1000 persons employed (25% of the total injuries). In 1956 rates were 6.3 per 1000 persons or 27.7% of the total injuries. In England in 1962 "manual handling" accounted for 25% of all reported industrial accidents while in France it accounted for 34% (64). In a 1972 survey (38), manual handling of objects accounted for about 23% of all work injuries in the United States (Table 4). In 1979 this figure was reduced to about 17% (39). In 59 back injuries from a number of Swedish firms,

Table 4. Sources of Work Injuries in 1972 (38)

	% of total
Handling of Objects (manual)	22.6
Falls	20.4
Struck by Falling/Moving Object	13.6
Machinery	10.2
Vehicles	7.1
Stepping on/Striking Against Objects	6.9
Hand Tools	6.1
Explosives	2.5
Elevators	2.2
Other	8.4

51% were due to lifting (51). In 100 cases of industrial back pain, 14 were due to "non specific" or straight lifting while 33 were due to twisting while lifting (21). A survey of 196 manual handling injuries revealed that 49% were due to lifting and 18% due to twisting or turning (53). A German study (25) found that pathological changes in a variety of body locations were 3.2 fold higher in manual handling personnel than bank employees.

Most other survey studies have concentrated on "low back pain". Summarizing a number of investigations Nachemson (36) estimated that 70-80% of the world's population suffer from low back pain at some point in their lives. The ages 21-50 yrs were those most affected (3, 7) with a decrease after age 50 (3,7a). About 40-50% of low back pain occurred in connection with lifting a heavy object or similar mechanical task but about half of these were from accidents involving violent movement or slips while carrying (23). Hult (24) found that 59 weight lifters lifting from 5-25 yrs had no higher incidence of back pain or veretebral degeneration than individuals doing light work.

It has been suggested that heavy manual labor could be a cause of low back pain and several studies have examined this question. Rowe (49) studied 237 men, ages 62-65 yrs, who were preretirees. He classified the men into two groups based on whether or not they had been treated for low back pain. About 27% of the men in the no treatment group had performed work classified as "heavy", but 40% of the men in the group that had been treated for low back pain had performed "heavy" work.

Lawrence (30) established a relationship between the number of years involved in heavy lifting, back pain and radiological changes. 221 miners, 99 dockworkers and yardworkers and 42 sendentary office workers were studied. An increase in the number of low back complaints was found in individuals who had

performed manual lifting for more than 30 yrs but not in those working less than 30 or less than 25 yrs. Days lost from work increased from 7% (of total sample) for those lifting less than 25 yrs to 19% for those lifting less than 30 yrs to 29% for those lifting over 30 yrs. Radiological changes classified as severe increased as years in lifting increased.

A series of studies by Anderson, Duthrie, and coworkers (7,9,10,43) have been summarized by Anderson (3). In surveys of 2,684 male employees in a number of occupations back pain was reported in 30% of the cases and low back pain in 76% of these (23% of total sample). The individual studies reported by these authors are of some interest. In one study (4) 340 miners in 4 specific job catagories were studied. In strippers and brushers, whose jobs required lifting of large quantities of coal and rock as well as working in stooped positions, 50.3% of the sample reported "rheumatic complaints". In underground haulers and surface workers, whose jobs required pushing of ore carts but no heavy lifting, 44.7% of the subject had "rheumatic complaints". In another study (5) of 1, 422 dockyard workers in 16 occupations, the complaint rate was not related to the "heaviness" of the work. Finally, a third investigation by these authors (43) involved 6 iron foundries, 7 occupational groups and 858 men. Iron moulders performed most of their work in a stooped position on the floor but their work also involved shoveling, kneeling, and heavy lifting. Machine moulders performed heavy, repetitive lifting in the upright position. Dressers and polishers performed "heavy" work in the upright position with little lifting involved. The other occupational groups had "light" physical work. 61.5% of the iron moulders, 34.7% of the machine moulders, 32.2% of the dressers and polishers and 37.0% of all other groups had rheumatic complaints.

Three prospective studies of injuries during industrial lifting have been performed. In the first investigations (10) 5 variables were studied: weight

history), isometric strength and lifting strength rating (LSR). LSR was equal to the maximal load on the job divided by the strength of a large strong man in the same body position. Thus as LSR approached 1.0 only a large strong man could do the tasks. In a pilot study of 135 people over a 5 month period it was found that jobs with the highest LSR had the highest incidence of low back injury. A larger study (9) of 411 people in 5 large electronics plants confirmed this finding. Individuals with a previous history of low back pain had significantly more low back incidence in this investigation.

In a subsequent study Chaffin (9a) evaluated 551 individuals in 6 industrial plants who had at least a 16 kg lifting requirement. Individuals were evaluated on 4 isometric strength tests three of which involved primarily the arms, legs and trunk musculature. The fourth test replicated the body and hand position found to be the one requiring the greatest amount of strength on the job. A "job strength rating" (JSR) was developed by dividing the average strengths of the workers into the maximum strength requirement of the job. The employee strength rating (ESR) was obtained by dividing the maximum strength requirement of the job by the individual's isometric strength. The subjects medical status was monitored by the plant physician during a 1.5 yr follow-up. It was found that as the JSR increased, the incidence of back injuries also increased. The incidence rate and severity rate of musculoskeletal and contact injuries increased when the index of weekly frequency of lifting multiplied by the ESR increased to a high value.

Keyserling et al. (27) performed a standardized biomechanical analysis of the jobs in an aluminum reduction plant. From this analysis the most stressful job elements were identified and their strength demands estimated. Nine strength tests were developed to simulate postures and forces required to

perform these lifted, frequency of lifting, personal factors (age, weight, height, medical tasks. Three hundred and forty-four incumbent and new employees were administered these strength tests and medically monitored on the job for 26 months (2.2 yrs); an ability ratio (AR) was calculated by dividing the force exerted on each strength test by the job requirement. Employees were classified into 3 groups based on how well their strength abilities matched job demands: "weak", "matched" or "strong". Injury incident rates were compared among the 3 groups by Chi Square analysis. Employees in the weak group suffered the highest injury incidence rate for 8 of 9 strength measures. Thus, workers whose strength abilities were less than the job requirement suffered more injuries than workers whose strength matched or exceeded job demands. There was no difference in incidence rate between workers whose strength match or exceed job demands.

The etiology of low back pain has not been determined but several findings are of interest. In the outermost layers of the intervertebral disc adjacent to the longitudinal ligament, nerve endings have been identified (23). Injection of normal saline into the disc of individuals with low back pain elicits the subjective symptoms of low back pain. A similar procedure with normal subjects produces no pain (22). Disc hernia is usually proceeded by attacks of low back pain (24). Degenerative changes of the disc can eventually be seen by roentgenogram in all subjects with low back pain but it is not possible to prove a direct relationship (36).

PREVENTION OF INJURIES

Prevention of injuries in material handling occupations in industry has traditionally been attempted by two major approaches: screening of workers before they are hired for the job and various measures taken on the job.

Screening Procedures

In various studies screening of workers has been performed by radiographic techniques, measurement of back curvature, isometric strength tests and medical history.

The radiographic screening technique presupposes that abnormalities noted in X-rays of the spinal column will place an individual at high risk of back injury. In one case, when individuals were screened for spinal abnormalities there was a reduction in the number of non traumatic back injuries in an industrial plant (12). However, several large epidemological studies (24, 29, 49, 55) have concluded that no developmental or degenerative index could be used to reasonably predict risk of back injury. Montgomery (35), in a review on the subject, concluded that X-rays are not helpful in reducing the incidence of low back injury. Also, the use of radiographic techniques entails the risk of radiation exposure.

There is one report in the literature of a technique called "lordosimetry" (63) which uses a relatively simple electromechanical device to measure the curvature of the spine while subjects are holding loads of various sizes. The theoretical rational for this device appears to be that large angular changes in the spinal curvature during holding of loads will predispose individuals to lumbosacral injury. However, this technique has not been tested for its predictive potential.

Isometric strength evaluation as a screening tool has been studied to a great extent. Nachemson and Lindh (37) found no significant difference in trunk flexor and trunk extensor strength between men with low back syndrome who had been incapacitated for 1 month and a control group. This suggests that isometric tests are of limited predictive value. However, as noted in the previous section certain indices developed from a variety of isometric strength tests can be used to predict risk of injury when the job is well defined in terms of the weight

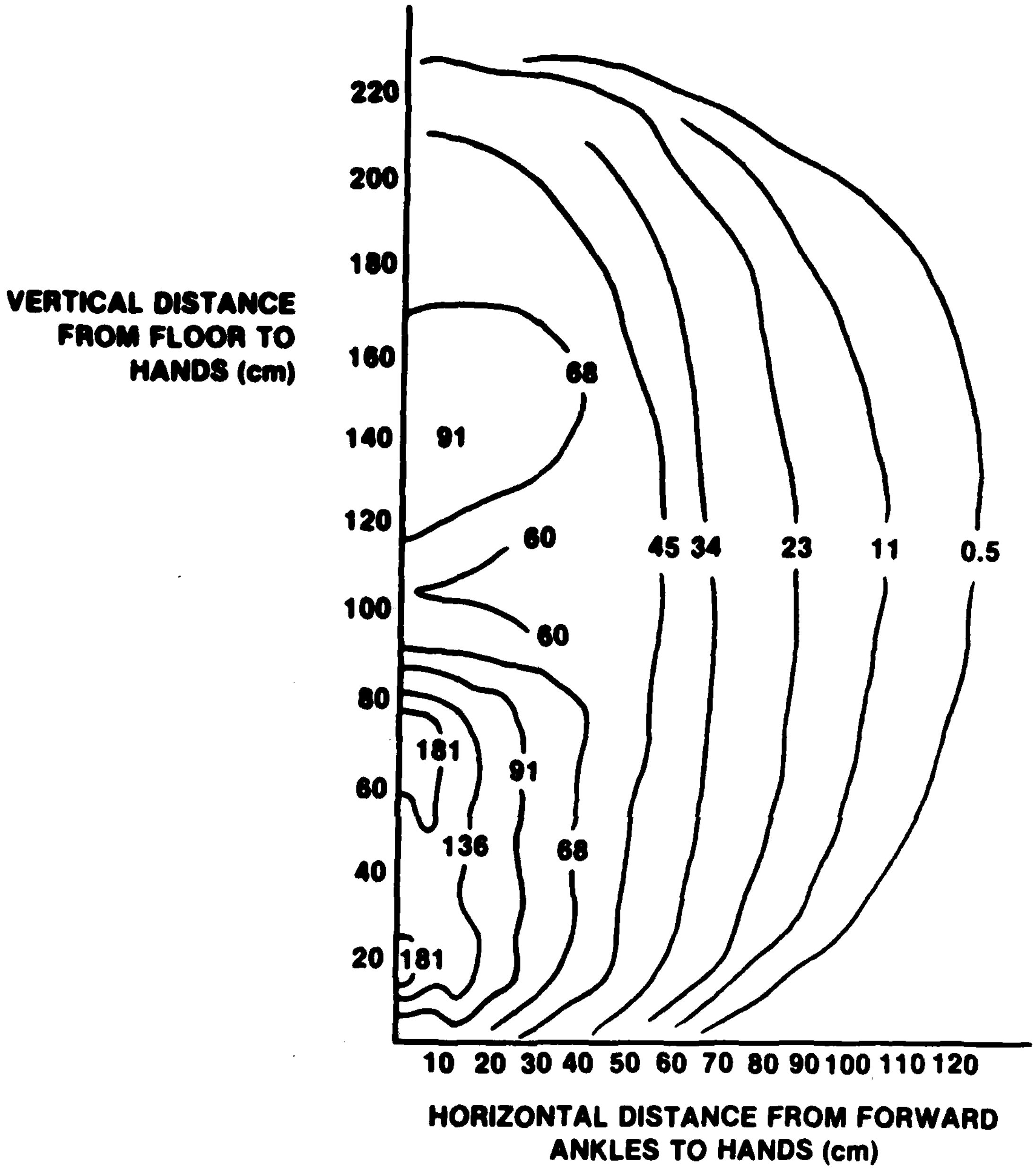

FIGURE 3. LIFTING STRENGTH FOR A LARGE, STRONG MAN. LINES INSIDE GRAPH DENOTE EQUAL STRENGTH (FROM CHAFFIN (9)).

lifted, body position required for the lift and the frequency of lifting. Three indices maybe of use: the lifting strength rate (LSR), the employee strength rating (ESR) and the ability ratio (AR).

The LSR is defined as:

$$LSR = \frac{L}{S}$$

where L is the maximum load required on the job and S is the strength of a large strong man in various body positions shown in figure 3. Chaffin and Park (10) found that if the LSR exceeded about 0.65 in an industrial setting, the incidence of low back injury increased. Assume a subject will not move the load further than 20 cm in front of his body. Figure 3 shows that the S value for this body position is 91 kg for a lift to knuckle height (76 cm (32)), 68 kg for a lift to shoulder height (144 cm (32)), and 34 kg for a lift to arms reach (216 cm (32)). With S = 91 and LSR = 0.65, L = 59 kg; with S = 68 kg and LSR = 0.65, L = 44 kg; with S = 23 kg and LSR = 0.65, L = 15 kg.

A second possible useful index is the ESR which is defined as:

$$ESR = \frac{L}{IS}$$

where L = load or the maximal strength requirement of the task and IS = an individual's isometric strength in three body positions. Chaffin (9) found that when this index was multiplied by the weekly frequency of lifting and this value exceeded 100, the incidence of injury increased.

A third index that may be of use is AR, defined as

$$AR = \frac{IS}{L}$$

where IS is the isometric strength in a defined body position based on the job to be performed and L is the maximal load on the job. Assume an isometric

strength evaluation consists of 1) an upright pull at 38 cm for a FK lift (test 1), 2) an upright pull with the arms at a 90° angle and the subject standing for the KS lift and (test 2), 3) an upright pull with the arms midway between shoulder height and full arm reach for the SA lift (test 3). L, defined by the LSR above is 59 kg for test 1,44 kg for test 2, and 26 kg for test 3. Keyserling et al. (27) found that when the AR was < 0.75 more injuries would occur (his "weak" group). Thus with AR = 0.75 and L = 59, subjects must score 44 kg on tests 1 to be allowed into a study. With AR = 0.75 and L = 44, subjects must score 33 kg on test 2. With AR = 0.75 and L = 15, subjects must score 11kg on test 3.

Rowe (49, 50) has stressed the advantages of medical histories in the screening of employees. He found a significantly higher incidence of low back problems in subjects who had previous episodes of low back problems. On the other hand Snook et al. (55) surveyed 192 Liberty Mutual Life Insurance loss prevention representatives for their most recent compensable back injury case. Firms obtaining medical histories and/or medical exams did not have a lower observed injury rate than firms not using these techniques. It was not clear from the questionnaire if the medical data was actually used in the selection procedure. Chaffin and Park (10) point out that one limitation to medical histories is that they depend on the individual's memory and motivation and may not always be considered reliable. In their study they found that individuals with a previous low back episode had significantly more low back incidence.

On the Job Prevention

Since the mid 1930's the staight back bent knee technique of manual lifting has been advocated (7a). The theoretical rational for this may involve the lower force exerted on the lumbar spine in this type of movement (see section entitled "Lifting Technique"). However, since this lift was introduced the incidence of

back injuries over the years has not been reduced significantly (7,7a). As noted earlier, in 1940 in Great Britian material handling injuries were 7.9 per 1000 persons employed (25% of total injuries) and in 1956 they were 6.3 per 1000 persons or 27.7% of total injuries. In a study by Snook et al. (55) it was found that firms that trained employees in "safe lifting procedures" were not significantly more successful in preventing back injuries than firms that did not train.

Snook (53) has determined that if a task is designed to fit at least 75% of population, two thirds of the current back injuries could be prevented. He presents extensive tables giving percentile distributions of MAL for different box sizes and lifting frequencies. Brown (7,7a) has emphasized that back injuries occur not only during lifting but also to a great extent in lifting and twisting, slipping with loads, and picking up loads the individual is not prepared for. The individual holding the load should be in control at all times. The exercise area should have good traction and be free of spills and obstructions.

SUMMARY

Investigations on injuries in material handling jobs suggest that individuals involved in repetitive lifting are at risk of back injuries, falls, and contact type injuries (3, 21, 25, 38, 39, 53). However, about half of the low back injuries are due to violent movements, twists or slips while carrying (7a, 21, 53). The studies of Rowe (49), Lawrence (30), and Anderson and coworkers (2, 4, 5, 43) suggest that the number of years involved on the job is more important in low back pain than acute trauma. Brown (7) also notes that low back pain seems to occur much more frequently as a result of natural or pathological causes than as a result of lifting. Working in a "stooped" position may also be a factor in low back pain (4, 43). The fact that individuals who have been weight lifting for 5-25 yr do not

have an increased incidence of low back pain (24) may suggest that careful lifting in standardized postures may avoid this malady. Prevention of injuries may best be achieved by screening of subjects prior to lifting and by proper engineering of the exercise environment. The most promising screening techniques are medical histories and certain indices developed from isometric strength tests.

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